METHOD AND SYSTEM FOR RADIO WAVE PROPAGATION CHARACTERISTICS
ESTIMATION AND RAY SPATIAL RESOLUTION CONTROL

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention relates to a method and a system for
a radio wave propagation characteristics estimation and a ray
spatial resolution control, and in particular to a radio wave
propagation characteristics estimation method, and a ray spatial
resolution control method in predicting the radio wave
10   propagation characteristics by a technique of geometrical
optics.

Description of the Prior Art

       A radio wave propagation simulator is employed to assist
the arrangement of a base station or a host system in a radio
15   communication system. The received power or delay spreading
at any receiving point can be estimated by using the radio wave
propagation simulator. On the basis of this estimation, an
installation site of an effective transmitting station is
determined, so that the overall efficiency can be enhanced by
20   reducing the number of base stations to be arranged.

       The radio wave propagation simulation is largely classified
into a statistical technique and a deterministic technique. The
statistical technique employs an expression for estimating the
propagation loss with the arguments of distance and frequency,
25   in which the parameters in the estimation expression are
determined on the basis of a large amount of data resulted from

actual measurements of the propagation loss in accordance with the statistical technique including the multivariate analysis. On the other hand, the deterministic technique is one in which the radio wave radiated from an antenna is regarded as an a

5   gathering of a number of radio wave rays and each ray is reflected and transmitted repeatedly on the geometrical optics, and propagated. The propagation loss and the amount of delay at an observation point can be obtained by synthesizing the electric power and the propagation time of the rays incoming to the

10   observation point.

       The deterministic technique is further largely classified into an imaging technique and a ray launching technique, depending on a way of keeping track of the propagation path. The imaging technique determines a reflection and transmission path of the

15   ray connecting between the transmitting and receiving points by obtaining an imaging point against the reflection surface. Since the reflection and transmission path is uniquely determined if the transmitting and receiving points and the reflecting and transmitting barriers are decided, the imaging technique can

20   search a strict propagation route of the ray.

       On the other hand, the ray launching technique is one in which the rays from the antenna are radiated at discrete angular intervals, irrespective of the position of the receiving point, and the ray passing near the receiving point through the repeated

25   reflection and transmission is regarded as the ray incoming to the receiving point. The ray launching technique solves approximately, but not strictly like the imaging technique, the propagation route of the ray connecting between the transmitting

and receiving points, and has a feature of shortening the time needed to search for the propagation route.

With the launching technique, first of all, a closed area is obtained around the transmitting antenna, and divided into
5   the partial spaces. Then, one ray is allotted to each partial space, whereby the partial space and allotted ray are regarded as identical. Thereafter, the propagation routes for a finite number of rays radiated from the transmitting antenna are tracked, and on the basis of its result, a situation of radio wave
10   propagation is estimated in an entire space around the antenna.

One example of dividing the closed area around the antenna into partial spaces was described in a literature written by Scott Y. Seidel, et al: "Site-Specific Propagation Prediction for Wireless In-Building Personal Communication System Design",
15   IEEE TRANSACTIONS VEHICULAR TECHNOLOGY, VOL. 43, NO. 4, NOVEMBER 1994, pp. 878-891.

In this literature, first of all, a three dimensional closed area of a regular icosahedron is provided around a transmitting antenna 301, as shown in FIG. 12. Next, a face making up the
20   regular icosahedron, namely, a plane of an equilateral triangle composed of the vertexes 406, 407 and 408 is extracted, and each side is divided into equal two lengths, using the points 409, 410 and 411, as shown in FIG. 13. By drawing the line segments parallel to the sides of the equilateral triangle having the
25   vertexes 406, 407 and 408 and passing at the division points, a similar triangle for the original triangle is newly created internally. The above processing is performed for all the faces constituting the regular icosahedron of FIG. 12. Then, the

vertexes of each equilateral triangle are moved in the direction of connecting the center of gravity in the regular icosahedron and the vertexes of each equilateral triangle newly created, so that there is an equal distance from the center of gravity,

5   as shown in FIG. 14, for example.

FIG. 14 is a view showing an instance where one side of the equilateral triangle making up each face of the regular icosahedron of FIG. 12 is bisected. Rays radiated from a transmitting antenna 501 located at the center of gravity in

10   the original regular icosahedron are radiated in each directions of connecting the transmitting antenna 501 and the vertexes of the polyhedrons of FIG. 14. In FIG. 14, as one example, a ray 504 passing at a vertex 502 is shown. At this time, a partial space 503 defined from the polygon of FIG. 14 and the transmitting

15   antenna 501 is regarded as identical to the ray 504.

FIG. 15 is a view showing a partial space 605 regarded as identical to a ray 601. At a point 602, the area of a section 603 perpendicular to the ray 601 is defined hereinafter as a spatial resolution at the point 602. The spatial resolution

20   at the point 602 is increased when the length between a transmitting antenna 604 and the point 602, namely, the propagation distance of the ray is greater. In this manner, a wide space is regarded as identical to one ray, whereby the radio wave propagation estimation precision by the ray launching

25   thecnique is decreased with larger propagation distance.

Thus, in order to maintain the spatial resolution at a certain value or below at any time, irrespective of the propagation distance, a method of dividing the ray propagating per a

predetermined distance was proposed. One example of this method was described in a literature written by Steven Fortune: "EFFICIENT ALGORITHMS FOR PREDICTION OF INDOOR RADIO PROPAGATION", in Proceedings of the 48th IEEE Vehicular

5   Technology Conference, May, 1998, pp. 572-576. FIG. 16 is a view for explaining the method as described in the above literature.

A triangular cone 712 of FIG. 16 is devided into a triangular cones 708 to 711, if the propagation distance of an allotted

10 ray 702 from a transmitting antenna 701 reaches a predetermined value. The rays 704 to 707 are allotted to the divided triangular cones, whereby the same processing is repeated subsequently. As a result, the spatial resolution can be kept at a certain value or below at any time, irrespective of the propagation

15 distance.

FIG. 17 is a view for explaining the operation of the ray launching technique in the case where an observation area 017, a transmitting point 015, a receiving point 016, and two objects 001 and 002 within the observation area are provided. In FIG.

20 17, for the simplicity, the operation is explained only in the two dimensional plane, but it is common that the operation is performed in the three dimensional space.

A ray radiated in a direction along a propagation route 003 at a discrete interval is incident upon the object 001 at

25 a point 018, so that a reflected ray 005 and a transmitting ray 004 are produced. The reflected ray 005 is further incident upon an object 002 at a point 019, so that a reflected ray 006 and a transmitting ray 007 are produced. Since the produced

ray 006 passes by the receiving point 016, the ray 006 is regarded
as incoming to the receiving point, a path consisting of the
paths 003, 005 and 006 is regarded as one of the propagation
routes connecting between the transmitting point 015 and the
5   receiving point 016.

Specifically, the receiving power and the incoming delay
time acquired from the propagation routes 003, 005 and 006 are
recorded in FIG. 18. In FIG. 18, the transverse axis 103
represents the delay time required for the ray to proceed from
10   the transmitting point 015 via the routes 003, 005 and 006 to
the receiving point 016, and the longitudinal axis 102 represents
the power strength of the ray having passed through the above
route. For the transmitting rays 004 and 007, the transmission
and reflection are repeatedly searched in the same manner as
15   in the propagation routes 003, 005 and 006. The ray that passes
by the receiving point 016 is treated as the incoming ray, as
in the propagation route 006, and the above processing is continued
till the search end condition is met.

The search end condition occurs when the received field
20   strength at the reflection and transmission point falls below
a predetermined value, or the total number of reflection and
transmission reaches a predetermined number of times. After
the ray radiated from the transmitting point 015 in the direction
toward the propagation route 003 is searched for the reflection
25   and transmission routes, the rays radiated in other radiation
directions such as the rays 008 to 014 are also searched for
the reflection and transmission routes. The rays are radiated
in all the directions as defined in advance, and searched for

the propagation routes, whereby a delay profile at the receiving point 016 can be obtained as shown in FIG. 19. In FIG. 19, the transverse axis 203 represents the time taken for the ray to go from the transmitting point 015 to the receiving point 016,

5 and the longitudinal axis 202 represents the power strength of the ray having passed through the above route.

The received power at the receiving point 016 is given by a total of power strength for all the paths as indicated in FIG. 19, and the delay spreading indicating the distortion is given

10 by the standard deviation of the delay time with a power ratio of the power strength to the received power in each delay time as the occurrence probability of the delay time.

Since the ray is regarded as identical to the partial space nearby the ray in the launching technique as described above,

15 when the ray is reflected from a barrier, it is considered that the same reflection has occurred in the partial space in the vicinity of the ray. Therefore, from a viewpoint of the estimation precision, it is desirable that the spatial resolution at the reflection point is set not to be too larger than the

20 area of the barrier. However, to improve the estimation precision, if the upper limit value of the entire spatial resolution is set at the minimum value of spatial resolution required when reflecting the ray from the barrier, there is a problem that the calculation time taken for the radio wave propagation

25 estimation is increased. The reason is that if the spatial resolution is reduced, a greater total number of rays are radiated and the total time for searching the route is increased.

On one hand, if the upper limit value of spatial resolution is set to be relatively large to suppress the calculation time required for estimation, there is a problem that the overall estimation precision may be degraded. The reason is that when

5   the ray is reflected from the barrier with a small spatial resolution, it is considered that the reflection also occurs even in the ray near area where the reflection does not actually occur.

BRIEF SUMMARY OF THE INVENTION

10   It is an object of the present invention to provide a method of shortening a required estimation time while preventing the degradation in the estimation precision, when an object environment for the propagation estimation is given in the ray launching technique.

15   According to one aspect of the present invention, there is provided a radio wave propagation characteristics estimation method of estimating the radio wave propagation characteristics by detecting a shield shielding a ray (radio wave) among a plurality of objects, wherein the plurality of objects are

20   provided in an observation area as defined in a three dimensional space, and the ray is radiated over the observation area, wherein a closed space confining the ray in a scene of the ray colliding with the shield is divided into a plurality of partial spaces, and a new ray confined by each of the plurality of partial spaces

25   is generated.

Also, according to another aspect of the invention, there is provided a ray spatial resolution control method for use in

estimating the radio wave propagation characteristics to adjust the spatial resolution of a ray (radio wave) in accordance with a certain criterion, when the ray collides with a shield shielding the ray among a plurality of objects, wherein the plurality of objects are provided in an observation area as defined in a three dimensional space, the ray is radiated over the observation area, and a space regarded as identical to the ray is provided in the vicinity of the ray, comprising a first step of detecting a collision point of the ray with the shield, a second step of determining whether or not to divide the space regarded as identical to the ray in accordance with the certain criterion, a third step of dividing the space regarded as identical to the ray into a plurality of partial spaces if it is determined at the second step that the space regarded as identical to the ray is divided, and a fourth step of allotting a ray regarded as identical to each of the partial spaces divided at the third step.

And the number of divisions at the third step is set to M (M is an integer of 2 or greater), and after the ray is allotted to the i-th (i is a number from 1 to M) partial space at the fourth step, the first to fourth steps are executed for each of the allotted rays, whereby the first to fourth steps are repeated successively until it is determined that the space regarded as identical to the ray is not divided at the second step.

Also, the criterion at the second step consists of a first criterion for examining whether or not the field strength at a collision point of the ray with the shield is greater than

or equal to a predetermined value, and a second criterion for examining whether or not an area ratio of a collided face of the shield to a cross section of the space in the vicinity of the ray taken by a plane containing the collided face of the

5   shield is smaller than or equal to a predetermined value. Further, the criterion at the second step further comprises a third criterion for examining whether or not the area of the cross section is greater than or equal to a predetermined value, and the angle (incident angle) of the ray with the normal to the

10   collided face is greater than or equal to a predetermined value.

Also, a conical form inscribed in a circular cone, and having a small error in volume from the circular cone is provided, with a central line of the conical form being a path of the ray, whereby the space in the vicinity of the ray is made up of the conical

15   form, wherein in dividing the space in the vicinity of the ray into a plurality of partial spaces at the third step, employing a plurality of similar conical forms for the conical form making up the space in the vicinity of the ray, the plurality of similar conical forms are disposed in the vicinity of the ray, so that

20   there may be a small error in the volume between the conical form making up the space in the vicinity of the ray and the sum of the plurality of similar conical forms for the conical form dividing the conical form.

Further, at the third step, a triangular cone is employed

25   as the conical form inscribed in a circular cone, and the size of the similar triangular cones is set so that a plurality of similar equal triangular cones for the triangular cone can be disposed inside the triangular cone without interstice. Also,

at the third step, a regular hexagonal cone is employed as the conical form inscribed in a circular cone, a similar regular hexagonal cone for the regular hexagonal cone is disposed at a center of the regular hexagonal cone, six regular hexagonal

5   cones identical to the similar regular hexagonal cone are disposed on the side faces of the similar regular hexagonal cone, with one side face abutting with the other side face, and the size of the similar regular hexagonal cones is set so that an error in the volume between a total of seven similar regular hexagonal

10 cones and the original regular hexagonal cone may be at minimum to dispose the similar regular hexagonal cones.

Still further, at the third step, a regular hexagonal cone is employed as the conical form inscribed in a circular cone, a similar regular hexagonal cone for the regular hexagonal cone

15 is disposed at a center of the regular hexagonal cone, six regular hexagonal cones identical to the similar regular hexagonal cone are disposed on the side faces of the similar regular hexagonal cone, with one side face abutting with the other side face, and the size of the similar hexagonal cones is set so that the outermost

20 contour side face of a conical form composed of a sum of seven similar regular hexagonal cones may be inscribed in the side face of the original regular hexagonal cone to dispose the similar hexagonal cones. Also, at the third step, a regular hexagonal cone is employed as the conical form inscribed in a circular

25 cone, a similar regular hexagonal cone for the regular hexagonal cone is disposed at a center of the regular hexagonal cone, six regular hexagonal cones identical to the similar regular hexagonal cone are disposed on the side faces of the similar

regular hexagonal cone, with one side face abutting with the other side face, and the size of the similar hexagonal cones is set so that the original regular hexagonal cone may be inscribed in the outermost contour side face of a conical form composed

5 of a sum of seven similar regular hexagonal cones to dispose the similar hexagonal cones.

According to a further aspect of the invention, there is provided a radio wave propagation characteristics estimation system for estimating the radio wave propagation characteristics

10 by detecting a shield shielding a ray (radio wave) among a plurality of objects, wherein the plurality of objects are provided in an observation area as defined in a three dimensional space, and the ray is radiated over the observation area, wherein a closed space confining the ray in a scene of the ray colliding

15 with the shield is divided into a plurality of partial spaces, and a new ray confined by each of the plurality of partial spaces is generated.

Also, according to another aspect of the invention, there is provided a ray spatial resolution control system for use in

20 estimating the radio wave propagation characteristics to adjust the spatial resolution of a ray (radio wave) in accordance with a certain criterion, when the ray collides with a shield shielding the ray among a plurality of objects, wherein the plurality of objects are provided in an observation area as defined in a three

25 dimensional space, the ray is radiated over the observation area, and a space regarded as identical to the ray is provided in the vicinity of the ray, comprising collision point detecting means for detecting a collision point of the ray with the shield,

determination means for determining whether or not to divide
the space regarded as identical to the ray in accordance with
the certain criterion, division means for dividing the space
regarded as identical to the ray into a plurality of partial

5   spaces if the determination means determines that the space
regarded as identical to the ray is divided, and allotting means
for allotting a ray regarded as identical to each of the partial
spaces divided by the division means.

      And the number of divisions by the division means is set

10   to M (M is an integer of 2 or greater), and after the ray is
allotted to the i-th (i is a number from 1 to M) partial space
by the allotting means, the collision point detecting means,
the determination means, the division means and the allotting
means are executed for each of the allotted rays, whereby the

15   collision point detecting means, the determination means, the
division means and the allotting means are executed repeatedly
and successively until the determination means determines that
the space regarded as identical to the ray is not divided.

      Also, the criterion in the determination means consists

20   of a first criterion for examining whether or not the field
strength at a collision point of the ray with the shield is greater
than or equal to a predetermined value, and a second criterion
for examining whether or not an area ratio of a collided face
of the shield to a cross section of the space in the vicinity

25   of the ray taken by a plane containing the collided face of the
shield is smaller than or equal to a predetermined value. Further,
the criterion in the determination means further comprises a
third criterion for examining whether or not the area of the

cross section is greater than or equal to a predetermined value, and the angle (incident angle) of the ray with the normal to the collided face is greater than or equal to a predetermined value.

5   Also, a conical form inscribed in a circular cone, and having a small error in volume from the circular cone is provided, with a central line of the conical form being a path of the ray, whereby the space in the vicinity of the ray is made up of the conical form, wherein when the division means divides the space in the

10   vicinity of the ray into a plurality of partial spaces, employing a plurality of similar conical forms for the conical form making up the space in the vicinity of the ray, the plurality of similar conical forms are disposed in the vicinity of the ray, so that there may be a small error in the volume between the conical

15   form making up the space in the vicinity of the ray and the sum of the plurality of similar conical forms for the conical form dividing the conical form.

       Further, in the division means, a triangular cone is employed as the conical form inscribed in a circular cone, and the size

20   of the similar triangular cones is set so that a plurality of similar equal triangular cones for the triangular cone can be disposed inside the triangular cone without interstice. Also, in the division means, a regular hexagonal cone is employed as the conical form inscribed in a circular cone, a similar regular

25   hexagonal cone for the regular hexagonal cone is disposed at a center of the regular hexagonal cone, six regular hexagonal cones identical to the similar regular hexagonal cone are disposed on the side faces of the similar regular hexagonal cone, with

one side face abutting with the other side face, and the size
of the similar hexagonal cones is set so that an error in the
volume between a total of seven similar regular hexagonal cones
and the original regular hexagonal cone may be at minimum to
5   dispose the similar hexagonal cones.

Also, in the division means, a regular hexagonal cone is
employed as the conical form inscribed in a circular cone, a
similar regular hexagonal cone for the regular hexagonal cone
is disposed at a center of the regular hexagonal cone, six regular
10 hexagonal cones identical to the similar regular hexagonal cone
are disposed on the side faces of the similar regular hexagonal
cone, with one side face abutting with the other side face, and
the size of the similar hexagonal cones is set so that the outermost
contour side face of a conical form composed of a sum of seven
15 similar regular hexagonal cones may be inscribed in the side
face of the original regular hexagonal cone to dispose the similar
hexagonal cones. Further, in the division means, a regular
hexagonal cone is employed as the conical form inscribed in a
circular cone, a similar regular hexagonal cone for the regular
20 hexagonal cone is disposed at a center of the regular hexagonal
cone, six regular hexagonal cones identical to the similar regular
hexagonal cone are disposed on the side faces of the similar
regular hexagonal cone, with one side face abutting with the
other side face, and the size of the similar hexagonal cones
25 is set so that the original regular hexagonal cone may be inscribed
in the outermost contour side face of a conical form composed
of a sum of seven similar regular hexagonal cones to dispose
the similar hexagonal cones.

According to a further aspect of the invention, there is provided a program for enabling the computer to perform a radio wave propagation characteristics estimation method of estimating the radio wave propagation characteristics by detecting a shield

5　shielding a ray (radio wave) among a plurality of objects, wherein the plurality of objects are provided in an observation area as defined in a three dimensional space, and the ray is radiated over the observation area, wherein a closed space confining the ray in a scene of the ray colliding with the shield is divided

10　into a plurality of partial spaces, and a new ray confined by each of the plurality of partial spaces is generated.

Also, according to another aspect of the invention, there is provided a program for enabling the computer to perform a ray spatial resolution control method for use in estimating the

15　radio wave propagation characteristics to adjust the spatial resolution of a ray (radio wave) in accordance with a certain criterion, when the ray collides with a shield shielding the ray among a plurality of objects, wherein the plurality of objects are provided in an observation area as defined in a three

20　dimensional space, the ray is radiated over the observation area, and a space regarded as identical to the ray is provided in the vicinity of the ray, comprising a first step of detecting a collision point of the ray with the shield, a second step of determining whether or not to divide the space regarded as

25　identical to the ray in accordance with the certain criterion, a third step of dividing the space regarded as identical to the ray into a plurality of partial spaces if it is determined at the second step that the space regarded as identical to the ray

is divided, and a fourth step of allotting a ray regarded as identical to each of the partial spaces divided at the third step.

The operation of the invention will be set forth below. In the invention, when a ray is propagated within a given observation area, and collides with a barrier residing on its path, a space in the vicinity of the ray is divided into a plurality of partial spaces until a predetermined condition is satisfied. With the conventional method, the partial space was divided in accordance with the propagation distance, irrespective of the reflection. However, with the inventive method, the partial space that is considered to cause a degradation in the estimation precision if dealt with uniformly is divided until there is less influence of degradation, whereby each of the subdivided partial spaces can be handled individually. Employing this inventive method, the estimation precision of radio wave propagation characteristics can be made better than the conventional method. On the other hand, in the case where there is possibly less influence of degradation in the estimation precision, the partial space is not divided, whereby if the initial value of spatial resolution is set to be relatively large, the total number of rays is reduced as compared with the conventional method in which the spatial resolution is evenly set at a small value to increase the estimation precision, so that the total calculation time taken for the propagation estimation can be shortened.

Because of the above features, in the invention, the spatial resolution can be controlled adaptively in accordance with the given estimation area. Accordingly, the estimation precision

can be increased and the calculation time shortened as compared with the conventional method.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flowchart showing an operation of an embodiment
5   according to the present invention;

FIG. 2 is a view for explaining a process of generating an intersectional plane between a partial space and a barrier;

FIG. 3 is a view for explaining a subdivision of a partial space in this invention;

10   FIG. 4 is a cross-sectional view showing an example of dividing the partial space in a first embodiment of the invention;

FIG. 5 is a view for explaining a process for obtaining a propagation direction of a ray allotted to the divided partial space;

15   FIG. 6 is a view showing an example of an incident angle characteristic for the reflectivity;

FIG. 7 is a diagram showing an example of a functional block of the invention;

FIG. 8 is a cross-sectional view showing an example of
20   dividing the partial space in a second embodiment of the invention;

FIG. 9 is a view for explaining an approximation of partial space with a circular cone;

FIG. 10 is a cross-sectional view showing an example of dividing the partial space in a third embodiment of the invention;

25   FIG. 11 is a cross-sectional view showing another example of dividing the partial space in the third embodiment of the invention;

FIG. 12 is a view showing an example of a closed area around a transmitting antenna;

FIG. 13 is a view for explaining a process for dividing the closed area around the transmitting antenna;

5 FIG. 14 is a view for explaining a radiation of a ray at a discrete interval;

FIG. 15 is a view showing an example of the ray and the partial space;

FIG. 16 is a view for explaining how to divide the partial 10 space by the conventional method;

FIG. 17 is an explanatory view of a ray launching technique;

FIG. 18 is a graph showing an example of a path profile of one ray at an observation point; and

FIG. 19 is a graph showing an example of the path profiles 15 of rays at the observation point obtained by the ray launching technique.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will be described below by reference to the accompanying drawings. 20 FIG. 1 is a flowchart showing an operation of an embodiment of the present invention, in which two routines A and B (818 and 819) are provided. In FIG. 1, it is supposed that an observation area is given in a three dimensional space, the objects such as walls and fixtures are provided within the observation area, 25 and a ray is radiated from a point P within the observation area in the propagation direction (step 802), and a flow up to

generating the reflected and transmitted rays at a reflection point is shown.

Herein, point P indicates the reflected or transmitted point in the ray launching technique or the position of a transmitting antenna, and specifically point 018, point 019, and transmitting antenna 015 in FIG. 17 that are cited in the description of related art. Also, when the point P is the transmitting antenna, the propagation direction indicates the discrete radiating direction provided around the transmitting antenna, and specifically directions 003, 008 to 014 in FIG. 17 as described in the description of related art, or a direction connecting the transmitting antenna 501 of FIG. 14 with each vertex of the polyhedron, for example, a direction of ray 504. On one hand, when the point P is the reflection or transmission point, the propagation direction indicates the direction of reflected ray or transmitted ray, and specifically the propagation routes 003 to 007 in FIG. 17.

First of all, a point at which a ray radiated from the point P in the propagation direction collides with an object within the observation area, namely, a reflection point, is searched and detected (steps 803, 804). Then, a determination whether or not a partial space regarded as identical to the ray incident upon the reflection point is subdivided into smaller partial spaces is made on the basis of a predefined criterion (hereinafter described) (step 805).

If the partial space is subdivided into smaller partial spaces, the partial space is subdivided into M (M is an integer) partial spaces in accordance with a predefined method

(hereinafter described) (step 806), and the procedure transfers to routine B (819) (step 807). If the partial space is not subdivided, the reflected ray and the transmitted ray are generated at the reflection point, and the procedure is ended

5   (steps 808, 809). Also, if the reflection point is not detected at step 804, the procedure is ended.

In routine B (819), an internal variable i (i= 1 to M) is first defined, and i is set to 1 as an initial value (step 811). Then, of the M partial spaces subdivided at step 806 in routine

10   A (818), the i-th partial space is selected (step 812). And a ray is allotted to the i-th partial space selected (step 820), and the propagation direction of the ray is calculated in accordance with the predefined method (hereinafter described) (step 813).

15   Herein, supposing that the ray allotted at step 820 to the partial spaces subdivided at step 806 is radiated from a starting point P in the propagation direction obtained at step 813, the procedure transfers to routine A again (818). In routine A (818), it is determined whether or not the divided partial spaces are

20   further subdivided, and if so, the subdivision processing is performed at step 805 again, and then the procedure transfers to routine B (819). If the subdivision is not performed, the reflected ray and the transmitted ray are generated (step 808), and the procedure is ended (step 809).

25   At step 814, the procedure transfers to routine A (818), and if routine A (818) is ended at step 809, the procedure transfers to step 815 immediately after that. At step 815, it is determined whether or not the value of the internal variable i is smaller

than M. If it is smaller than M, i is incremented by 1 (step
817), and other partial space is selected (step 812). If the
value of i is greater than or equal to M, routine B (819) is
ended (step 816).

5   At step 807, the procedure transfers to routine B (819).
If routine B (819) is ended at step 816, the procedure transfers
to step 809 immediately after that, where one nested routine
818 is ended. The above processing is performed until it is
unnecessary to subdivide the partial space at step 806.

10   Referring now to FIGS. 2 to 5, a specific operation of an
embodiment of the invention as shown in FIG. 1 will be described
below. FIG. 2 is a view for explaining a process of generating
an intersectional face between a partial space and a barrier.
A ray 902 radiated from a point 901 collides with the barrier
15 906 at a point 903. A line 908 is the normal to the barrier
906, and an angle 907 indicates the incident angle of the ray
902 upon the barrier 906. At this time, the intersectional face
905 is generated by the partial space 904 near the ray 902 and
the barrier 906. FIG. 2 shows an instance where a space around
20 an antenna is divided by a triangular cone.

    FIG. 3 is a view for explaining the subdivision of the partial
space in this invention. Herein, an instance is shown where
θ is equal to 0 in FIG. 2. FIG. 3A shows an intersectional face
1212 (slant line portion) that is generated by a barrier 1212
25 and a section 1211 of the partial space, as a result of the ray
902 being incident upon a point 1213. One example of the criterion
(i.e., criterion at step 805 in the flowchart of FIG. 1) for

determining whether or not the partial space 904 is subdivided at the point 903 is as follows:

(1)   The electric field strength of the ray at the point 1213 is greater than or equal to a predetermined value.

5   (2)   The area ratio of the intersectional face 1212 to the partial space section 1211 is smaller than or equal to a predetermined value.

(3)   The area of the partial space section 1211 is greater than or equal to a predetermined value, and the incident angle 907

10   of the ray 902 is greater than or equal to a predetermined value.

Basically, if (1) and (2) of the above three items are satisfied at the same time, the partial space 904 is divided (subdivided). In addition to these two criteria, the criterion (3) may be further added, whereby the partial space may be divided

15   (subdivided) if three criteria are satisfied at the same time.

A method of deciding the propagation direction of the ray allotted to the subdivided partial space (i.e., method of calculating the direction at step 813 in the flowchart of FIG. 1) is made in the following manner. Firstly, the partial space

20   is divided at any point on a line segment connecting the points 903 and 901 by a plane perpendicular to the ray 902. A section 1309 of the partial space of FIG. 4 resulting therefrom is divided into M (M=4 in this example) similar regions 1305 to 1308, and a center of gravity in each region is obtained, like the points

25   1301 to 1304. Also, the like center of gravity is obtained for another sectional face of the partial space. Connecting the confronted centers of gravity, a desired propagation vector 1901 is obtained as shown in FIG. 5.

FIGS. 3 to 5 show an instance where M is equal to 4, but an instance where M takes another value may be dealt with in the same way.

When the partial space 904 is subdivided in this manner,
5   the cross section of the partial space at the reflection point 903 is shown in FIG. 3B. On the basis of the flowchart of FIG. 9 and the above criteria for division, the partial space 1202 is not divided anymore, and the ray allotted to the partial space 1202 is not reflected from the barrier 1212, but passes at the
10   point 1206, and continues to proceed till it collides with other barrier. This partial space 1202 is not divided because no reflection point is detected at step 804 in the flowchart of FIG. 1. In particular, the ray allotted to the partial space 1202 passes at the point 1206 and is not reflected from the barrier
15   1212.

On one hand, the partial space 1203, which meets the above criterion, is extracted as shown in FIG. 3C, further subdivided, and then subdivided as needed in the same manner.

The effects of this embodiment will be described below.
20   In this embodiment, the area ratio of the intersectional face between the partial space and the barrier to the cross section of the partial space at the reflection point is used as the criterion for division, and the region where no reflection occurs in practice can be divided and handled in another way (criterion
25   (2)). Though the reflectivity of radio wave is typically increased rapidly with greater incident angle, as shown in FIG. 6, the region where the ray is incident upon the barrier at different angle with greatly varied reflectivity can be divided

and dealt with in another way by employing the criterion with the incident angle of the ray (criterion (3)).

The estimation precision of the ray launching technique can be enhanced due to the above effect. On the other hand,

5   since the subdivided partial spaces are analogous to the original partial space, the same processing can be repeated in the subsequent subdivision process, thereby simplifying the process. Further, since the partial space before subdivision is given by the sum of subdivided partial spaces, the total space around

10   the antenna can be estimated without interstice.

From the processing operation as described above, a functional block for implementing this processing operation is obtained as shown in FIG. 7. Referring now to FIG. 7, the functional block is composed of a collision detection section

15   1, a partial space division determination section 2, a partial space division section 3, a partial space ray allotting section 4, a control section (CPU) 5, a RAM (Random Access Memory) 6, and a ROM (Read Only Memory) 7.

The collision detection section 1 has a function of detecting

20   the collision of the ray with the shield (barrier). For instance, in FIG. 3, the ray collides with the barrier 1212, and the presence or absence of collision can be determined by solving simultaneously an expression as defined in the three dimensional space representing the face of the barrier 1212 and an expression

25   as defined in the three dimensional space representing the ray.

The partial space determination section 2 has a function of determining whether or not the space regarded as identical to the ray is divided in accordance with the criterion. The

partial space division section 3 has a function of dividing the space into a plurality of partial spaces in accordance with the above criterion. The partial space ray allotting section 4 has a function of allotting the ray regarded as identical to each
5   of the divided partial spaces.

The control section 5 is the CPU (corresponding to the central processing unit of the computer), in which the control section 5 reads an operation control program stored in a storage medium of the ROM 7, and controls each of the sections 1 to 4 in accordance
10   with a control procedure of this program, employing the RAM 6 that is a working memory to execute the operation processing as shown in FIG. 1. Namely, the program controls the operation of the CPU, and the CPU under the program control is instructed by the program to perform each processing as described above.

15   A second embodiment of the invention will be described below by reference to the drawings. In the first embodiment, the space around the antenna is divided by the conical form so that the partial space is severed by a plane perpendicular to the ray as shown in FIG. 4. On the other hand, in the second embodiment,
20   the space around the antenna is divided so that the partial space is severed as shown in FIG. 8. In FIG. 8, an instance of M=7 where the partial space is subdivided into similar regular hexagons 1409 to 1415 of a regular hexagon 1408 is shown. The regular hexagons 1409 to 1414 are contact with the vertexes of
25   the regular hexagon 1408 at the middle points 1416 to 1421 of their sides, and after division, the ray allotted to the partial spaces pass through the centers of gravity 1401 to 1407 for the regular hexagons 1409 to 1415.

In the case where a relatively circular figure is employed like the regular hexagon used in this second embodiment, a determination whether or not the ray is taken in when the ray passes in the vicinity of the receiving antenna can be simplified,

5   resulting in greater processing rate. The reason is that this determination is typically made by checking to see whether or not the receiving antenna is contained inside the partial space in the vicinity of the ray. Thus, if the partial space is approximated by a circumcircle 1601 of the regular hexagon 1602

10   that is a sectional plane perpendicular the ray, as shown in FIG. 9, this determination results in examining the distance between the receiving antenna and the ray, whereby the simplification of determination process can be accomplished.

Next, a third embodiment of the invention will be described

15   below by reference to the drawings. In the case where the space around the antenna is divided to have the cross section of the partial space as shown in FIG. 8, comparing a cross section 1408 before division with a sum area of the partial spaces after division gives rise to excessive and deficient areas as indicated

20   by the slant line in FIG. 8. Thus, a division form in which the partial space after division does not lap out of the partial space before division is shown in FIG. 10.

On one hand, a division form in which there is no interstice between the partial space after division and the partial space

25   before division is shown in FIG. 11. In FIG. 10, the size of regular hexagon after division is set up so that the vertexes 1801 to 1812 are inscribed in the regular hexagon 1813. On the other hand, in FIG. 11, the size of regular hexagon after division

is set up so that the regular hexagon after division intersects at the middle points 1501 to 1506 of the sides for the regular hexagon before division.

In particular, when the division form of FIG. 11 is employed, the radio wave propagation situation in the space around the antenna can be estimated without interstice.

Though various examples of dividing the partial space have been described above, a conical form with a small error in volume from the circular cone is provided among the conical forms inscribed in the circular cone, with its central line being the path of the ray, whereby the space in the vicinity of the ray is made up of the conical form, and when the space in the vicinity of the ray is divided into plural partial spaces, employing plural similar conical forms for the conical form making up the space in the vicinity of the ray, the plural similar conical forms may be disposed in the vicinity of the ray so that there is a less error in volume between the conical form making up the space in the vicinity of the ray and the sum of plural similar conical forms that are analogous to the conical form and divided from this conical form.

As described above, according to the present invention, there is the effect of making it possible to increase the estimation precision and shorten the calculation time efficiently by adjusting the density of rays with the ray launching method more flexibly than with the conventional method. The reason will be as follows. Though the density of rays is adjusted uniformly in accordance with the propagation distance in the conventional method, the density of rays is increased till the

degradation is judged to be small in the case where the density of rays is so small in reflection or transmission that the estimation precision is degraded in the present invention. Thereby, the increased calculation time due to generation of

5   unnecessary rays can be suppressed so far as the estimation precision is not degraded.